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ON THE POSSIBILITY OF ACCELERATING POSITRON ON AN ELECTRON WAKE AT SABER

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Abstract

A new approach for positron acceleration in non-linear plasma wakefields driven by electron beams is presented. Positrons can be produced by colliding an electron beam with a thin foil target embedded in the plasma. Integration of positron production and acceleration in one stage is realized by a single relativistic, intense electron beam. Simulations with the parameters of the proposed SABER facility [1] at SLAC suggest that this concept could be tested there.

INTRODUCTION

Physics of electron acceleration in plasma has been studied through theoretical analysis and numerical simulations. Plasma can support accelerating field orders of magnitude larger than conventional accelerator. The E167 PWFA experiment at SLAC, demonstrated that electrons can be accelerated by up to 43GeV in a 85cm long plasma [2].

For a plasma-based e^-/e^+ linear collider, ultra-high gradient acceleration of positrons and electrons are equally important. Compared to electron acceleration, positron acceleration has been less studied, due to the lack of available relativistic positron beams.

Until now, positron acceleration by a plasma wake has focused on plasma waves driven by single positron drivers, which are fundamentally different from those driven by electron drivers in the non-linear regime. Simulations show that the accelerating fields driven by positron drivers are two to five times less than those driven by electron drivers with similar parameters [3]. Meanwhile, due to the phase mixing of returning plasma electrons, the non-uniformity of focusing field can lead to emittance growth of the accelerated bunch. Plasma waves driven by electron drivers in the non-linear regime offer striking advantages: large accelerating field, linear focusing field, and radially independent accelerating field in the accelerating structure [4]. To utilize those advantages, we present a new approach for positron acceleration in the highly non-linear plasma wave driven by a relativistic, intense electron beam (Fig. 1). In this scheme, plasma electrons are expelled by the space charge field of an electron beam driver and pulled back by the newly created ion column. The returning plasma electrons form a density concentration region, approximately one plasma wavelength behind the beam head, which can provide focusing and accelerating fields for positrons.

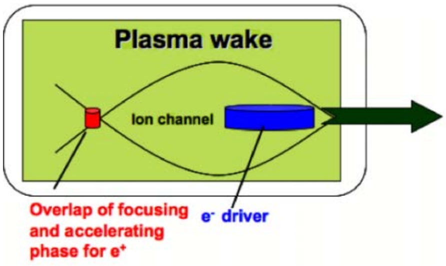

Figure 1: Schematic of positrons acceleration in the wake of an electron beam

POSITRONS GENERATION

Positrons are produced through pair production by a relativistic, intense electron beam colliding with a thin high-Z material target (such as Tantalum). To model the generation of positrons in the target, the Monte-Carlo EGS5 code [5] is used, which simulates the energy loss of the beam particles through ionization, Bremsstrahlung and pair production. This code also models the emittance growth of the primary beam and generates the full phase space of the generated positrons.

With this code, a typical simulation uses 500μm Tantalum target to balance positron yield and degradation of the primary electron beam. EGS simulations show that the spatial profile of the positron beam generated follows that of the primary electron beam, and that the positron yield is about 4.2% (Tab. 1). In addition, there is about 2% emittance growth of the primary electron beam due to collisions with Tantalum nuclei. The energy profile of positron beam emerging from conversion target has a Maxwellian distribution with a 100% energy spread (Fig. 2).

Table 1: 3D simulation parameters

Beam parameters after collision with target	
e^- Beam charge	2×10^{10}
e^+ Beam charge	6.8×10^{8}
Spotsize σ_x/σ_y (μm)	2.5/0.8
Bunch length (μm)	28
e^- Beam Emittance $\varepsilon_{Nx}/\varepsilon_{Ny}$ *(mm·mrad)*	93/14
e^+ Beam Emittance $\varepsilon_{Nx}/\varepsilon_{Ny}$ *(mm·mrad)*	20/5

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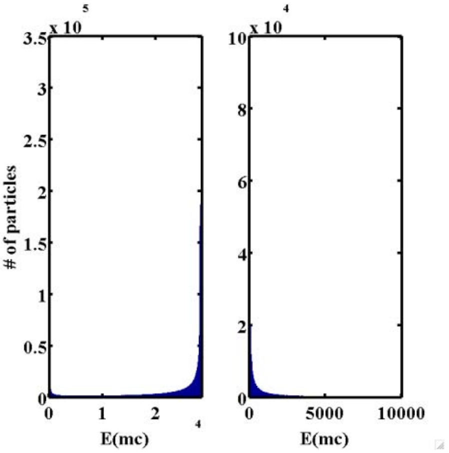

Figure 2: EGS simulation of the primary e^- bunch (left) and produced e^+ bunch (right) energy profiles emerging from the 500μm Tantalum target.

In addition, EGS simulations also show that the positron beam leaves the foil target with a small transverse size and relatively small angular divergence. To allow for an efficient trapping of positrons, the foil target is placed inside the plasma. The target should have a high atomic number Z to generate positrons effectively. It must also endure the repetitive impacts of the electron beams.

SIMULATIONS

2D cylindrical symmetric particles-in-cell simulations with a primary bunch with 2×10^{10} electrons and mono-energetic positron beam show that 1.78×10^{7} positrons are trapped and accelerated to a maximum energy of 1.75GeV over 4.56cm of plasma [6]. To model realistic beam parameters, including beam emittance and energy profile, e^- and e^+ particles data (x, y, z, p_x, p_y, p_z) obtained from EGS simulations are imported into the 3D particles-in-cell code OSIRIS [7]. We start with 2×10^{10} primary electrons and 6.8×10^{8} positrons. The plasma density is chosen to be 2.8×10^{17}/cm^3, the same as in the E167 experiment [2]. These fully 3D simulations show that a peak accelerating field for positrons of 60 GV/m can be reached (Fig. 3a), considerably larger than that created by e^+ beam driver with similar parameters. The focusing region for positrons is very narrow, since most positrons are defocused by the ion column (Fig. 3b). Figure 3c shows that z=60μm, where positron bunch is trapped, the accelerating field is independent of r, and Figure 3d shows that the focusing field is linear with r. Figure 4a and 4b show an x-z slice and P_z-z distribution of the positrons at plasma entrance, respectively. As seen in Figure 4b and Figure 4d, a small fraction of the positrons (about 4×10^{6}) is trapped with a 35% energy spread after a 9.2cm of plasma. Figure 5 indicates that the average energy gain by the e^+ bunch increases linearly with plasma length, while the energy spread decreases.

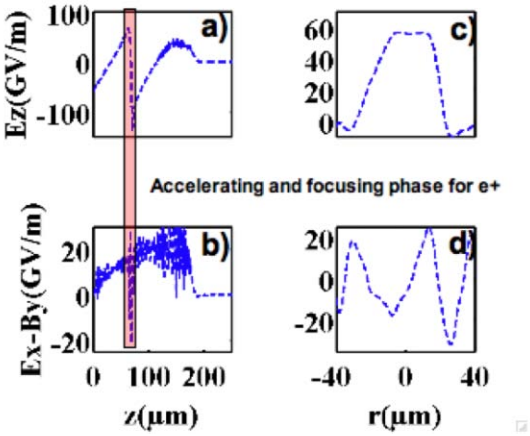

Figure 3: 3D simulation results at s=9.2cm: (a) longitudinal field *vs* z at axis (b) transverse field *vs* z at r=10μm (c) longitudinal field *vs* *r* at z=60μm where the trapped positron bunch is located (d) transverse field *vs* r at z=60μm.

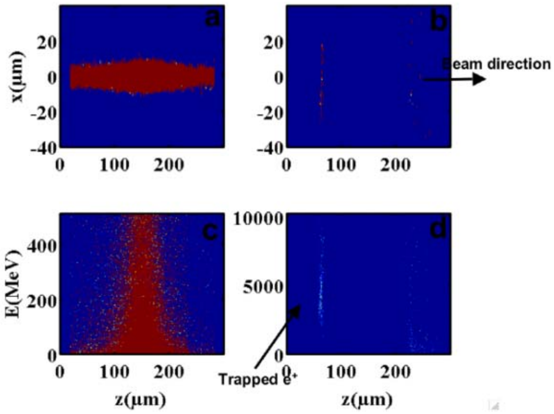

Figure 4: Realspace *r* vs *z* of e^+ at (a) s=0 (b) s=9.2cm; *Pz* vs *z* of e^+ at (c) s=0 (d) s=9.2cm.

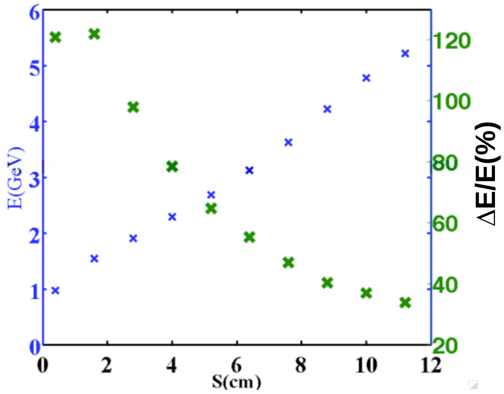

Figure 5: Average energy gain by the e^+ bunch (blue), and energy spread (ΔE/E) (green) *vs* plasma length.

CONCLUSION

This paper investigates the possibility of positron acceleration in non-linear plasma wakes driven by an electron beam driver. Simulations show that up to 4×10^6 positron are trapped, focused and accelerated. This number suggests that this scenario could be tested in future experiment with the SABER beam line.

Future studies will investigate the possibility of using a drive beam witness beam scheme to maximize the number of trapped e^+ and optimize the quality of the e^+ bunch emerging from the plasma.

The approach presented here provides a convenient means to study physics issue for a possible e^+ plasma wakefield accelerator driven by an e^- beam. The ultimate realization of this scheme would likely entail an injected short e^+ witness beam rather than a self-trapped bunch, as described here.

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